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EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG

David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS

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Ottawa

J. A. PEARCE
Head Astronomer
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Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

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THE TEMPERATURE OF THE SOLAR CHROMOSPHERE

By WILLIAM PETRIE

THE notion of temperature in a stellar atmosphere is complicated by departures from thermodynamic equilibrium. The mere fact that a spectral line is formed indicates that temperature equilibrium is not realized. Consider what is meant by a state of thermodynamic equilibrium. Suppose we have an assemblage of atoms and ions at a given temperature T. Atoms in a certain energy level A may absorb radiant energy and be raised to a higher level B. After a short interval, these atoms return to level A and emit energy. Atoms in the lower level may also reach level B by collision with an electron. In this case, the electron rebounds with lessened energy. Furthermore, atoms in the higher level may return to level A by collision with an electron. These electrons rebound with increased energy. If the assemblage is in thermodynamic equilibrium, then the number of absorptions from A to B equals the number of emissions from B to A, and the number of collisional excitations from A to B equals the number of collisional de-excitations from B to A. Under these conditions no spectral lines are formed.

There is much evidence that appreciable departures from thermodynamic equilibrium are present in stellar atmospheres. The hot stars of classes O and B show spectral lines characteristic of differential temperature conditions; the range is of the order of 35,000°. The effect is even more pronounced for the planetary nebulae and Wolf-Rayet stars. In the case of the latter objects, Aller[1] finds a range in temperature of as much as 100,000°. The determined value is a function of the element studied and its par-

[1] *Astroph. Journal*, vol. 97, p. 135, 1943.

ticular stage of ionization. The great range in temperature exhibited by these objects undoubtedly means that we are referring to different depths in the stellar atmosphere.

For a gas in thermodynamic equilibrium, all methods of calculating temperature yield the same result. This is not the case in stellar atmospheres. It is well known that the colour of an incandescent body changes with temperature, due to the fact that the proportions of the various colours radiated are altered as the temperature changes. In other words, the shape of the energy curve is a function of temperature. This energy curve is obtained quantitatively from Planck's law, which gives the intensity of radiation per unit solid angle in a wave-length interval $\Delta\lambda$ at wave-length λ for a temperature T, i.e.,

$$I_\lambda \Delta\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \Delta\lambda,$$

where h = Planck's constant,
k = Boltzmann's constant,
c = the velocity of light.

The colour temperature of a star is obtained by comparing the observed spectral energy curve with theoretical curves computed from Planck's law. The theoretical curve which includes the stellar temperature will match the observed curve.

The effective temperature, on the other hand, is calculated from Stefan's law, an expression which gives the total radiation in ergs per second from a unit area of radiating surface, i.e., $E = \sigma T^4$,

where $\sigma = 5.672 \times 10^{-5}$ ergs cm.$^{-2}$ deg.$^{-4}$ sec.$^{-1}$.

It is a simple matter to calculate the effective temperature of the sun from Stefan's law. The solar constant is the amount of solar radiation received per unit area of the earth's surface per second in a direction normal to the surface. This constant is corrected for absorption effects of the earth's atmosphere. The total radiation emitted by the sun over a sphere is then $4\pi R^2 F$ where R is the distance from earth to sun and F is the solar constant. If r is the radius of the sun, the surface area is $4\pi r^2$. Then by Stefan's Law $4\pi R^2 F / 4\pi r^2 = \sigma T^4$. Substituting the known values of R, F, r and σ, we find that T is around 5750°.

The difference between colour and effective temperature could be explained if we properly understood the absorption processes that take place in stellar atmospheres. The discovery by Wildt[2] that the negative hydrogen ion is an important source of opacity, and the recent calculations by Williamson[3] of the absorption coefficient of this ion, have reduced the discrepancy between observed and theoretical colour temperatures, but the agreement is not yet perfect. The negative hydrogen ion consists of a neutral hydrogen atom combined with a second electron. This ion may absorb sufficient energy to remove the electron which then becomes free. Since the electron can be given a continuous range of velocities, that is, its energy is unquantized, the negative ion may absorb continuous radiation.

It is not always possible to obtain accurate spectrophotometric measures of the continuum over a considerable wave-length range and hence derive colour temperatures. Furthermore, the calculation of effective temperatures requires a knowledge of the sizes and brightnesses of the stars in question. In the absence of these data, we must resort to other means of determining temperature.

The presence of line and continuous emission in stellar spectra is a great aid in calculating temperatures. Consider the origin of continuous emission. At high temperatures, ionization and recapture processes are active. That is, atoms may absorb sufficient energy to lose one or more electrons. The atoms are then ionized. However, the resulting ions recombine with free electrons and become neutral atoms. Since the energies of free electrons are unquantized, the radiation resulting from recapture processes will form a continuum. The intensity distribution in this continuum depends upon the velocity distribution of the free electrons, and measures of the spectral gradient determine the electron temperature of the atmosphere. It is interesting to note that the electron temperature in the atmosphere of a planetary nebula is much less than the temperature of the central exciting star. The atmosphere of a planetary contains nitrogen, oxygen and neon, and the atoms of these elements possess metastable energy levels. The atoms can reach such levels only by collision, and not by absorption of radiation, hence atoms

[2] *Astroph. Jour.*, vol. 89, p. 295, 1939.
[3] *Astroph. Jour.*, vol. 96, p. 438, 1942.

are excited by collision at the expense of the energy of the free electrons. The result is a reduction in electron temperature.

Line emission is the result of two different mechanisms. We have already explained that ionization followed by recapture produces continuous emission. The same process also produces line emission, since an electron may be captured in a high energy level and cascade to lower levels. The intensities of emission lines produced by this mechanism indicate the temperature of the radiation producing the ionization, hence the term ionization temperature. Emission lines may also arise from line excitation and subsequent cascading. That is, atoms in a certain initial level may absorb radiation and be transferred to a higher level. After a short time these atoms drop back to lower levels and emit radiation. The intensities of these lines give the temperature of the radiation producing the observed populations of the various energy levels. This value is the excitation temperature.

Departures from thermodynamic equilibrium are negligible for the ionized portion of a stellar atmosphere. The absence of absorption of radiation by electrons and collisions between these particles, brings about a close approach to a Maxwellian distribution. The temperature of the electron gas then approximates the temperature of the incident radiation.

There is evidence that the solar chromosphere is not in thermodynamic equilibrium. Menzel[4] obtained an excitation temperature of around 4400°, while Menzel and Cillié[5] derived an electron temperature of 10,000° from intensities in the Balmer continuum. The work which follows shows that departures from thermodynamic equilibrium are appreciable even for the metallic atoms.

The data used were obtained by the Harvard-Massachusetts Institute of Technology Eclipse Expedition to Siberia in 1936. A description of the instruments used and the general results of the eclipse have been published.[6] The eclipse spectrograms were calibrated by means of a standard lamp, and the task of reducing the data to emission intensities in ergs was performed chiefly by W.P.A. workers.

[4] *Pub. Lick Obs.*, vol. 17, p. 271, 1931.
[5] *Astroph. Jour.*, vol. 85, p. 88, 1937.
[6] *Harvard Annals*, vol. 105, p. 87, 1936.

In the absence of self-reversal, emission line theory is relatively simple, and measured emission intensities provide useful data for determining excitation temperatures. The emission in ergs per second from an emitting volume of 1cm^3 is

$$I = \frac{64\pi^4\nu^4}{3c^3}\frac{N_o}{\omega_o}e^{-\chi_n/kT}S_{nn'},$$

where ν = the line frequency,
c = the velocity of light,
N_o = the number of atoms in the ground level for a particular stage of ionization of the element in question,
ω_o = the statistical weight of the ground level,
χ_n = the excitation potential of the upper level involved in the production of the line,
k = the Boltzmann constant,
T = the excitation temperature,
$S_{nn'}$ = the theoretical line strength.

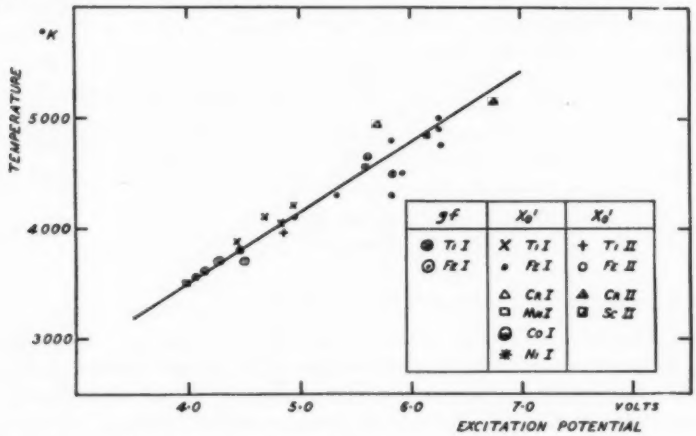
The chromospheric data are divided into multiplet groups of the same excitation potential, and for the lines of each group, a plot made between $\log I$ as abscissa and $(4 \log \nu + \log S)$ as ordinate. Each plot now differs by the Boltzmann factor $5040\Delta\chi/T$, where $\Delta\chi$ = the difference in excitation potential between the multiplet groups.

A vertical shift superimposes each plot, and we have now essentially a curve of growth for emission lines. The various line segments are fitted to the master curve by a vertical shift, the amount of the shift, Δy, being equal to $5040\Delta\chi/T$. The excitation temperature is then determined from the relation $\Delta y = 5040\Delta\chi/T$.

Simple emission line theory is complicated by self-reversal. That is, the chromosphere cannot be treated simply as a radiating layer of gas, since the emitted radiation is partially reabsorbed by other chromospheric atoms. An accurate treatment of the problem requires the solution of the equation of transfer. However, since we use a curve of growth for emission lines, the simple method outlined here is valid.

Both King's laboratory strengths and Menzel's solar strengths are used in the temperature determinations which are carried out for FeI, FeII, TiI, TiII, MnI, ScII, NiI, CoI, CrI, CrII. The figure

shows that the temperature of the chromosphere determined from a given exposure is a function of the excitation potential of the data used, and that the temperature range for the metallic atoms considered is of the order of 1500°. The chromospheric data consist of intensities from a series of exposures taken as the eclipse proceeded.



The intensities, then, refer to different heights in the solar atmosphere. Temperatures determined from the data of different exposures are essentially constant, which indicates that the range in temperature with height in the chromosphere is small as far as the metallic atoms are concerned.

This may not be true for the lighter gases, hydrogen and helium. It is important to determine temperatures for these latter elements at different heights in the chromosphere. The Edlén coronal theory demands high temperature in the outer parts of the solar atmospher and an increasing chromospheric temperature with height seems necessary. A temperature discontinuity is unlikely. The foregoing work indicates that temperature must be introduced as a parameter when discussing the physics of the chromosphere.

Physics Department,
University of British Columbia,
November, 1943.

GREEK ASTRONOMY—ITS BIRTH, DEATH, AND IMMORTALITY

By W. Carl Rufus

THE period of Greek astronomy lasted about a thousand years, from Thales 600 B.C., to Hypatia 400 A.D. That period witnessed its birth, growth, and death; its resurrection in Europe awaited another millennium.

The Greeks inherited a large amount of astronomical and astrological raw material chiefly from the Akkadians, Chaldeans, Babylonians, and Egyptians. George Sarton, eminent American historian of science, says, "Science is the human mirror image of nature." But the pre-Grecian image of the heavens was distorted. The zodiac circled the sky with imaginary animals, and circumscribed human life with fantastic ideas. The celestial sphere was filled with superhuman beings that controlled the destiny of men and nations. In general, the priestly class were the star-gazers. Much of their raw material has little interest to astronomers, but part utilized by the Greeks, has permanent value.

The predecessors of the Greeks noted the recurrence of astronomical events, the rising and setting of the sun, the waxing and waning of the moon, the changing seasons, the convolutions of the wandering stars. To establish a calendar they tried to harmonize the natural time units, the day, the month, and the year, which are incommensurable. They recorded observations of stars and planets and of unusual phenomena as eclipses, conjunctions, and occultations. The Egyptian calendar, we are told, was settled in 4236 B.C. The pyramids were oriented by the stars. One of Egypt's chief contributions was a system of land measurement or geometry. The Babylonians contributed a system of celestial measurements based on the sexagesimal scale which is still used in time and circular measure. The 360° circle was probably due to the nearness of that number to the length of the year in days. The practical Chinese, whose science apparently did not influence the Greeks, divided the circle into 365¼ degrees.

Greek Astronomy brought into sharp contrast the practice of the East and the West. In the East the priests monopolized knowledge, insulated it from the people by the occultism of magic, divination, and astrological formulas. The Greeks freed the intellect. Reason and imagination began to assert themselves. They loved knowledge, trusted the conclusions of logic, peered into the occult and the obscure, and learned that nature is not erratic but orderly, rational, and understandable. The Greeks sought to explain the recurrence of astronomical events by means of motions reduced to law. They classified and correlated phenomena, their knowledge was set in order, they attempted to formulate a unified system of thought regarding the universe, or a nature-philosophy, which constituted the true beginning of physical science, in which astronomy played an important role.

Thales of Miletus, western Asia Minor, is distinguished as the first natural philosopher and the first absent-minded star-gazer to fall into a pit. His knowledge came chiefly from Mesopotamia and Egypt, countries he visited as a successful merchant. He predicted an eclipse observed at Miletus in 585 B.C., which won for him special recognition. The method was probably obtained from the Babylonians. He also learned some geometry from the Egyptians, which he further developed and applied to practical problems. He wrote a handbook on nautical astronomy. His race, the Ionians, were good sailors and his mother was a Phoenician.

Thales sought a philosophical or cosmological ultimate that would unify all things. The fundamental element was water or moisture. Its evaporation formed air. It permeated germs, the source of life, and nourishment, which sustains it. His associate, Anaximander, postulated eternal motion and speculated regarding evolution. Another Miletan, Anaximenes, rejected water as the primal essence and substituted *pneuma* or breath, a sort of living air. Heraclitus of Ephesus proposed a cosmology based on change or flux. In his system everything changes, nothing endures, but the restless change of all things.

Not so the imaginary concrete atoms of Leucippus and Democritus, the indivisibles of philosophic materialism, as unreal to a scientist as

Hamlet's ghost. The universe was composed of these indestructibles and a connecting or separating void, likewise unreal, vague, and intangible. These imaginary concrete building blocks were used to construct the foundation of Epicurean doctrine, which emphasized the void rather than anything concrete in science.

Pythagoras left Ionia in search of a more satisfactory philosophy. At Croton in lower Italy he joined a Dorian colony. He and his followers adopted four cosmological elements—earth, water, air and fire. They developed geometry, adding much, including the famous Pythagorean theorem. The writings of Philolaus of Tarentum have preserved their doctrines, which were based quite largely on a correspondence between the workings of man's mind and the workings of nature. Number was fundamental in the structure of the universe.

Philolaus has received credit by some authors for advocating the motion of the earth, even its revolution around the sun. It is true that he imagined the earth in motion, but also the sun and other bodies, around a non-existent central fire. The motions were not real nor heliocentric. Moving at fancied related distances, the celestral bodies gave forth "the music of the spheres." The mystical idea of Pythagoras, that the heavenly bodies including the earth are spheres, conforms with modern doctrine. Hicetas of Syracuse shared the idea that the earth moves. He held, moreover, that the heavens, sun, moon and stars are standing still and that their apparent motions were due to the earth's turning and twisting on its axis.

About 400 B.C., Athens took the leadership in Greek thought. During the preceding century, the Golden Age of Pericles and the poet Euripides, Anaxagoras migrated from Ionia to Athens and neglected wealth for science. He explained the moon's phases, also lunar and solar eclipses. Religionists resented his teachings and he prudently returned to Asia Minor. Socrates remained at Athens and was condemned to drink the poison hemlock for his impiety. At his death, however, the reaction he inaugurated against a still-born mechanical philosophy developed into Plato's Doctrine of Ideas. Plato's philosophy emphasized ethics, but included mathematics and astronomy. Astronomy owes a great debt of gratitude to Plato—he proposed the problem to reduce the motions of the heavenly bodies

to mathematical law. And science owes much to astronomy, because it was the only subject at that time with a large amount of data to reduce to law. Pythagorean metaphysics imposed the condition of a combination of uniform circular motions, a notion that held 2000 years until the time of Kepler's elliptical orbits. Eudoxus proposed a geocentric solution based on a system of homocentric spheres with axes tipped to carry the individual planets on secondary and multiple spheres to represent their motions. Then he introduced an important scientific method—*he made observations to test his theory.*

Aristotle followed and obstructed the stream of astronomical progress for two millennia. He congealed the mathematics of Eudoxus into crystalline spheres, because the soul cannot exist without a body. To the elementary concentric spheres—earth, water, air and fire—he added ether; then came seven crystalline spheres for the planets, an eighth for the stars and finally the *primum mobile,* which imparted motion to the entire universe. . Outside this was the Unmoved Mover. He taught that bodies fall according to their weight. Experiments 2000 years later by Galileo proved that to be erroneous. Philoponos of Alexandria, sixth century A.D., denied that heavier bodies fall more quickly and referred to experiment, but the authority of Aristotle prevailed. Aristotle also rejected the revolution of the earth around the sun, arguing correctly that such a motion would cause the stars to show an annual change of direction. This annual parallax, too small to be observed by the Greeks, was first measured in 1838. His positive conclusion based on negative evidence was good logic but poor science.

The Peripatetics continued to *peripatein* in circles trodden by Aristotle, preserving and commenting on his works. The Stoics and the Epicureans, added little to science excepting a Socratic contempt, which ended with the adoption of their teachings with many of Plato and of Aristotle, in the syncretic system of Neoplatonism, which reached its zenith in the fourth century A.D.

Alexander the Great, who was a pupil of Aristotle for a short time, founded Alexandria in 332 B.C. Here Greek science migrated and was to a great extent free from the toils of moral philosophy. Euclid's Elements of Geometry was not grist for Athenian disputa-

tion, but it inspired Archimedes of Syracuse, who visited Alexandria not long after Euclid's death, to become the leading mathematician of his day. He also mastered geocentric astronomy and made an ingenious mechanical contrivance to illustrate the motions of the heavenly bodies. Aristarchus of Samos was one of the pioneer scientific teachers at Alexandria. His heliocentric theory has earned for him the title of the Ancient Copernicus. But it brought against him the Grecian charge of impiety, and his doctrine was rejected in favour of the geocentric theory of Plato and Aristotle. Another advocate of the heliocentric doctrine was Seleucos, a Babylonian. Aristarchus was the first to apply a scientific method to determine the relative sizes and distances of the moon and the sun. Although his method was sound, inadequate observations led to results too small in the case of the sun. The librarian Eratosthenes determined the size of the earth by measuring the distance from Alexandria to Syene (modern Assuan), and the angle at the earth's centre subtending this arc. There is some doubt regarding the accuracy of the result, due to the uncertainty of the length of the unit used; but it seems probable that the error was less than one per cent. He also suggested the circumnavigation of the earth, a feat first accomplished by the ships of Magellan. He determined the obliquity of the ecliptic within about seven minutes of the true value.

Mathematical contributions in astronomy included the relationships between the fundamental great circles of the celestial sphere; viz., the horizon, the meridian, the ecliptic and the equator. It remained, however, for Hipparchus of Nicea, second century B.C., who erected an observatory at Rhodes, to devise the coordinates, longitude and latitude on the earth, and corresponding right ascension and declination in the sky, and to invent the principles of trigonometry, essential to the solution of many of the problems of the sphere.

The contributions of Hipparchus mark him as one of the greatest astronomers of all races and all time. He developed the epicycles of Appollonius of Perga as the basis of his solution of the problem of motion of the heavenly bodies. This scheme was more successful than the homocentric spheres of Eudoxus in depicting the motions

and determining the positions of the sun, moon and planets. He improved the theory of the motion of the sun and the moon and increased the accuracy of predicting eclipses. A new star in Scorpio inspired Hipparchus to make a star catalogue, which contained 1080 positions newly determined. He classified stars according to apparent brightness into six magnitudes which are still used. By comparing his measured star positions with earlier ones, he discovered the precession of the equinoxes. He was preceded in this discovery, however, by Kidinnu, a Babylonian. More and better observational data were required to solve some of the perplexing problems of planetary motion, so Hipparchus with true scientific foresight and devotion made and recorded new observations for posterity.

No substantial progress in astronomy was made for three centuries after Hipparchus. Posidonius, a Stoic, who was born about the time of Hipparchus' death, made a new determination of the size of the earth, which did not surpass the work of Eratosthenes. A limited heliocentric theory—that Mercury and Venus revolve about the sun —was revived and termed Egyptian, although it was advocated earlier by Heracleides of Pontus, one of Plato's disciples, who also held that the earth rotates on its axis once a day.

The Caesars brought astronomy as well as other products of the Greek mind into the service of the Roman Empire. Julius Caesar, with the aid of the Alexandrian astronomer, Sosigenes, established the Julian Calendar based on the Eudoxian year of 365¼ days. To him we owe the leap year and the renaming of the Roman fifth month, July. August was so named in honor of his successor.

Commentaries, compendiums, and astrological works were the chief products during this drab period in science to the second century A.D. Hero of Alexandria, c. 100 A.D., possessed scientific ability but employed his genius chiefly in devising mechanical toys; e.g., his magic pitcher operated by the principle of the siphon, his whirligig turned by steam, and a contrivance used to illustrate his repertoire of mechanical devices, gleaned chiefly from the practical work of Archimedes on the level, the pulley, and the screw. In optics he demonstrated the fundamental law, that the angle of incidence equals the angle of reflection, and applied it in his *dioptra*,

which was used in surveying in connection with the water level. Instruments used by the Greeks and adopted by the practical Romans included the sundial and the water-clock. But the science of the Latins was a poor imitation of the Greek and was cultivated chiefly for practical use; e.g., in calendar making, navigation, and agriculture.

The work of Hipparchus, the greatest Greek astronomer, was preserved by Claudius Ptolemaeus, second century A.D., the greatest scientific writer of the Greeks. Ptolemy made some original contributions, notably on atmospheric refraction, also discovered evection, which is an inequality of the moon's motion near quadratures. He developed planetary theory, especially by the introduction of a hypothetical point called the equant. In the case of Mercury, the imaginary equant had motion in an imaginary circle. So the geocentric solution of Plato's problem, like his Idea in Philosophy, became complicated and subjective, rather than direct and objective in its nature. Its chief scientific salvation was that it "saved the phenomena."

Ptolemy's *Megale Syntaxis,* or Great Composition, contains the astronomical doctrines developed by the Greeks and constitutes the masterpiece of the constructive period of Greek natural philosophy. The Ptolemaic system of the universe was geocentric. The moon's distance was 59 times the radius of the earth, next came Mercury and Venus, then the sun at a distance about 20 times that of the moon, or about 1/20 its true value; beyond the sun were the three remaining planets, Mars, Jupiter, and Saturn, surrounded by the crystalline unchangeable sphere of the stars, which was actuated by the all-embracing *primum mobile* of Aristotelean philosophy. Submerged were the partial heliocentric system of Heracleides of Pontus and others and the clearly defined heliocentric doctrine of Aristarchus. A few astronomers had attempted to keep alive the spirit of observation. During the latter half of the first century A.D., Menelaus of Alexandria made observations even in imperial Rome; and in the first half of the second century, Theon of Smyrna made observations of Venus and Mercury.

Ptolemy's world geography, illustrated by maps which are lost, but have been reconstructed from his data, was more useful than his

Syntaxis in the expansion of the Roman Empire. His astrological treatise, the *Tetrabiblos,* produced a more profound effect on the philosophy of the Latins than his sound scientfic work.

A century before Ptolemy, the Stoic Manilius wrote an elaborate astrological poem, and in the fourth century A.D. Firmicus Maternus compiled a text of astrology. This trend was more potent than the work of Theon of Alexandria, who wrote a commentary on Ptolemy's *Syntaxis.* The effect of this scientific work was largely offset by his astrological contemporaries, Paul of Alexandria and Hephaestion of Thebes. Hypatia, the talented daughter of Theon, represented the last stage of Greek science. The sole ancient mathematician of her sex, she commented on the algebra of Diophantus and the astronomy of Ptolemy. The last able representative of Neoplatonism, which was an early rival of Christianity, she was murdered by a Christian mob in 415 A.D., and her martyrdom marks the death of the Greek productive period.

Little effect remained in Christian Europe. The church fathers had imbibed some of the doctrines of Neoplatonism which included Plato's Idea and Aristotle's Natural Philosophy. Origen harmonized Alexandrian science with early Christian theology in its nascent stage, although his work was finally condemned. St. Augustine succeeded where Origen failed. As a Manichaean initiate for nine years during his youth and young manhood, his mind was steeped in that syncretic system, which attempted to fashion a world religion by combining elements of the current ethnic faiths including mystical Mithraism, dualistic Zoroastrianism, some Oriental occultism, Greek rationalism, and Pauline doctrines of Christianity. At 29 years of age, he went to Rome and soon afterward to Milan. Here he embraced Neoplatonism and next he adopted Christianity. He succeeded in forming the first widely accepted Christian synthesis. Emphasis was placed on spirit as the ultimate reality. The phenomena of nature became unworthy of special consideration. The individual soul and its relationship to God became central in Patristic thought, and theology dominated science and philosophy for a thousand years. Rome had vanquished Greek individualism and chained Greek thought to the wheels of empire. Christianity freed the individual soul and

centered philosophy upon its worth. The outward and upward objective view was obstructed by an inner sphere more rigid and opaque than Aristotle's crystalline wheelwork of the heavens. The Dark Ages settled over Europe, with only a faint gleam here and there, a feeble reflection of the glory that was Greece.

We have witnessed the birth, growth and death of Greek natural philosophy in Europe. For two centuries following Thales, nature-philosophy had dominated Greek thought. Socrates renounced this doctrine and emphasized ethics. Then Plato and Aristotle attempted to harmonize these conflicting fields but failed, possibly because their chief emphasis was on ethics. The school at Alexandria developed separate systems of science, ethics and religion.

Science, however, was merely a philosophical system regarding nature. It had no knowledge concerning natural forces and consequently could not use them for practical purposes. For that reason the Romans were indifferent to scientific activities and Greek inspiration failed. Stoicism and Epicureanism competed for supremacy in philosophy and ethics. Stoicism emphasized the human will and held that man's destiny is controlled by knowable influences, which gave a fillip to astrology. Epicureanism emphasized the fundamental nature of their eternal atoms which placed man's fate at the mercy of their philosophical materialism. Neoplatonism, decided in favour of an indeterminate fate, which was more compatible with the doctrine of free will of early Christianity. The Greek system of thought, which was quite rational and scientific, was replaced by a composite system predominantly idealistic and mystical. So we bury the body of Greek doctrines regarding nature in European soil for a thousand years.

But the spirit of Greek science migrated eastward. The Persian school at Jundeshapur during the fifth and sixth centuries harboured Nestorian Christians and Neoplatonists. Greek writings were translated into Syriac and lived again. Then came the mighty Moslem movement when Arabic became the vehicle of human expression. First from the Syriac, next from the Greek came translations of the immortal works of Aristotle, Plato, Euclid, Ptolemy and others. Bagdad became the centre of learning. Here under the patronage of the Caliphs were collected not only the classical and scientific works

of the Greeks, but also the wisdom of the more ancient East. Something has been learned regarding the contributions from India, including the Hindu numerals, known long afterward in Europe and America as Arabic numerals, so thorough was the work of assimilation. How much was contributed by the Chinese has never been completely investigated. We know, however, that Chinese astronomers served on the staff of the Bagdad Observatory and at other Moslem centres; and we are fully convinced that Chinese astronomical instruments were the best in the world until the time of Tycho Brahe's Castle of the Heavens near the end of the sixteenth century. At Bagdad Christians, Jews, Greeks, Persians, Indians and Chinese collaborated.

A new synthesis of knowledge was in the making, more comprehensive than that attempted by the Greeks; it was a mingling of the East and the West—a world synthesis. Carried westward again, it flourished in Northern Egypt under the Fatimid rulers and far beyond into Spain with the victorious march of Islam. Translations from Arabic into Latin made available the accumulated knowledge of the East and the West and offered the basis for a comprehensive world-wide system. But the European mind was unschooled in Eastern wisdom and quite content to select elements of its own liking akin to its long-neglected buried treasure. Even "Arabic" numerals were anathema in some institutions; e.g., Florence and Padua. So a world-wide synthetic system was rendered impossible; what resulted has been styled a Greco-Arabic synthesis. In this system it seems quite evident that Islamic was used in the initial stage, but the Greek finally predominated and the Far Eastern element was largely rejected. The Chinese compass was, of course, accepted and applied in navigation. Their powder was diverted from harmless fire crackers and fireworks to destructive guns and cannon.

Translations at first from Arabic into Latin, including Greek science brought about a revival of learning in European centres. Original Greek texts were eagerly sought and some were found, including the works of Aristotle, Galen, Hippocrates and Ptolemy. These were translated into Latin and became the inspiration and chief subject of study of the new and rapidly developing universities of

Europe. The *Syntaxis* of Ptolemy translated into Arabic was styled, not the Great Composition, but *Al Magisti*, the Greatest, and it was honoured by that superlative title, the *Almagest*, when it was translated into Latin and later into English and other modern languages.

As astronomy was the only subject during the productive period of Greek philosophy that possessed a large body of accumulated data, so during the revival of learning in Europe it was the only subject that possessed the essentials of a science—methods of measurement, accumulated data, formulated laws and doctrines, and a developed technique to test the correspondence between theory and observation. All of this was to a great extent a return to the method of the scientific astronomers of the Greeks. We note especially Eudoxus, who formulated his homocentric theory of the motion of the heavenly bodies and erected an observatory to obtain data to test his theory; Eratosthenes, Aristarchus, and above all Hipparchus, who was especially skilful in applying the geocentric theory based on epicycles and eccentrics; and when he had exhausted all available data of his predecessors, supplemented by a large amount made in his own observatory, he patiently made records to hand down to posterity. The revival of this spirit of direct observation of nature soon led to the methods of modern science in which experiment replaced tradition, and nature became the final authority as the arbiter of natural law.

The Greek urge for natural knowledge, its rugged individualism, its confidence that the universe is rational and may be interpreted by law, its faith in Aristotelean logic and the conclusions of the human reason, came to life again in Mediaeval Europe. The birth and death to Greek science culminated at last in a glorious resurrection and assured immortality.

University of Michigan.
December 22, 1943.

ADJUSTING THE POLAR AXIS

By Cyril G. Wates

THE possessor of a telescope on an equatorial mounting, and provided with setting circles, should be justified in assuming that he has only to set the scales to the correct declination and hour angle to find the desired object in the field of view. Too often this is far from the case. The field of an astronomical telescope is so small that unless the polar axis is exactly parallel to the axis of the earth, and the optical axis at right angles to the polar axis, the setting circles may prove more of a nuisance than a help, especially if the object is too faint to be identified with certainty in the finder. All this has been pointed out by Mr. H. Boyd Brydon in an article entitled "Setting up and Adjusting the Equatorial Reflecting Telescope," which appeared in Vol. XXXVII of this Journal. Mr. Brydon has performed a very valuable service for amateur telescope makers by assembling in one article a wealth of information from different sources, together with many excellent suggestions of his own.

There is, however, a special case in which the tried and trusted methods described by Mr. Brydon are not easily applicable. This is the case of the double-yoke and similar mountings in which the telescope tube cannot be reversed end for end. Mr. Brydon has pointed out to me in correspondence that the Polar Axis of such a mounting may be lined up by means of plumb lines, but this involves two steps: first, adjusting the optical axis of the main mirror so that it coincides exactly with the axis of the *outside* of the tube; second, transferring the axis to the plumb lines by means of gauges. I feel that this method, while theoretically correct, is open to considerable inaccuracy in actual practice. Therefore I venture to suggest a method which I have used with complete success in lining up my own 9-inch reflector, and also the 12½-inch telescope at the University of Alberta, which has a double-yoke mounting provided with adjustment screws in all directions.

It should be remembered that the tube of a reflecting telescope is simply a mechanical device for holding the various optical parts, and that it makes no difference to the working of the instrument

whether the optical and mechanical axes coincide or not. I do not mean by this statement that every effort should not be made to obtain coincidence; I mean that it should not be necessary to depend upon the accuracy of this coincidence to determine the alignment of the Polar Axis. If a telescope can be turned to any part of the sky and give correct readings on the setting circles, our object has been attained, no matter what the relation between tube and optical parts may be. The method I shall describe does exactly this—it is what may be called a "proof of the pudding is the eating" method, and it is equally applicable to all types of mountings, although it was designed primarily for the double-yoke.

Consider a telescope equatorially mounted at the North Pole. The Polar Axis should be exactly vertical. If the tube is moved in declination so that the horizon bisects the field of view, and then clamped in this position, the telescope may be rotated on the Polar Axis through a complete circle without altering the relationship of the horizon and the field of view. Our ability to perform this test is complete proof of the correct setting of the Polar Axis.

Since all directions from the North Pole are south, we must determine our settings in R.A. by means of meridians of longitude. Pointing the telescope towards Greenwich, we are looking along the zero meridian. Diametrically opposite is the 180th meridian. At two other points on the horizon are the 90th and 270th meridians. Assume the Polar Axis to be tilted 5° towards Greenwich. It will be necessary to raise the tube 5° in declination in order to view the horizon. When the telescope is rotated on the Polar Axis, after being thus raised, the field of view will be *above* the horizon everywhere, except in the longitude of Greenwich. Conversely, if the Polar Axis is tilted towards the 180th meridian, the tube must be depressed in order to view the horizon in the direction of Greenwich, and at all other points the field of view will then be *below* the horizon.

If the Polar Axis is tilted towards the 90th meridian, and the tube set to view the horizon in the direction of Greenwich, the field of view will be *below* the horizon at the 90th meridian, *above* the horizon at the 270th, and *on* the horizon at the 180th. The converse case is obvious.

At the pole, the horizon coincides with the celestial equator; therefore the result of our imaginary experiment may be stated thus: if an equatorial mounting may be turned through a complete circle on the Polar Axis with the celestial equator bisecting the field of view in all directions, the Polar Axis is parallel to the axis of the earth. A moment's consideration will show that this statement may be modified by substituting for "complete circle," "any large arc of a circle"; and for "celestial equator," "any parallel of declination."

If the celestial equator were marked on the sky by a luminous line, or even by a number of easily identified stars, it would be a simple matter to apply our North Polar method of adjustment to any part of the world, but unfortunately this is not the case. It might, however, be possible to point the telescope at an equatorial star near the eastern horizon and follow it across the sky until it set, but this would mean many hours of observing on many nights, and is quite unnecessary. The actual procedure is much simpler and the whole job may be finished in a single clear evening.

Briefly, the practical application of the principles already explained is this: the declination scale is set to give correct readings for stars on the meridian and near the equator, after which the apparent declination of two stars is measured, one exactly three hours east, the other exactly three hours west of the meridian. The errors, or differences between the apparent and true declinations, are substituted in two very simple formulae, one of which gives the direction in which the Polar Axis requires to be tilted to correct any existing error; the other gives the amount of tilt. An actual illustration will clarify the method. I am indebted to Mr. E. S. Keeping, Assistant Professor of Mathematics at the University of Alberta, for working out the equations.

The observations were made about the middle of September. Three stars were selected from Norton's Atlas, and the right ascensions noted, as follows:

A ..... α Pegasi	R.A. $24^h\ 0^m$
B ..... α Aquilae	R.A. $19^h\ 46^m$
C ..... α Herculis	R.A. $17^h\ 11^m$

These stars were chosen from the following considerations: Star B (Altair) crosses the meridian at about 9 p.m. in September. Star A (Markab) is 45° east of the meridian 14 minutes later. Star C (a close double) is 45° west of the meridian 11 minutes later still. All three stars are easily identified, all are near the equator but somewhat north, to reduce the refraction errors to a minimum.

When star B was a few minutes east of the meridian, it was brought to the centre of the field, using a high-power eyepiece, and the scale adjusted to give the correct declination reading for this star. The star was followed until the moment of transit, and the declination scale again checked for correctness.

The telescope was then swung to the east, and star A was brought to the centre of the field and followed until it was exactly 45° east of the meridian, as shown by the interval of 14 minutes since the observation was made on star B. The *apparent* declination was noted, and the telescope swung into the west, to repeat the same observation on star C, the apparent declination of which was noted 11 minutes later. The results were recorded as below:

	True Decl.	*Appar. Decl.*	*Error*
Star A	14° 40′	14° 50′	$+10'$ $(+.17°)_{\mu_E}$
Star B	8° 36′	8° 36′	0
Star C	14° 30′	13° 55′	$-35'$ $(-.58°)_{\mu_W}$

Note that the errors are positive if the apparent declination is greater than the true declination, negative if less. Note also that the errors are reduced to decimals of a degree. The symbols are those to be used in the equations given below.

Now let δ be the direction in which the upper end of the Polar Axis requires to be tilted to correct both errors, and ϵ be the angle through which it must be tilted. The angle δ is to be measured in degrees from the meridian, and since this angle is found from its sine, it may have two values. The value less than 90° is always to be used for our purpose. It will be necessary to determine in which of the four quadrants the angle is to be set off. More about that later. Here are the equations for δ and ϵ.

$$\sin \delta = 0.38 \frac{\mu_W - \mu_E}{\sqrt{\mu_W{}^2 + \mu_E{}^2 + \sqrt{2}(\mu_W \mu_E)}},$$

$$\epsilon = \sqrt{3.4(\mu_W{}^2 + \mu_E{}^2) + 4.8 \mu_W \mu_E},$$

Substituting the values for the errors observed, with due attention to the signs, we have:

$$\sin\delta = 0.38 \frac{-.58 - .17}{\sqrt{.34 + .03 - (1.4 \times .58 \times .17)}} = -.601.$$

Referring to a table of sines, we find that

$$\delta = -37^\circ \text{ (or } -143^\circ).$$

This means that the top of the Polar Axis required to be tilted in a direction 37° from the meridian, but it does not tell us in which quadrant the angle is to be measured. To ascertain this, take the sum of the errors μ_W, μ_E with due attention to sign, and call it D. In this case, D is −.41°. Now refer to the following table.

D	δ	*Quadrant*
Pos.	Pos.	S.E.
Neg.	Neg.	N.W.
Pos.	Neg.	S.W.
Neg.	Pos.	N.E.

Since D and δ are both negative, the top of the Polar Axis must be tilted into the N.W. quadrant, in a direction 37° west of north.

The next step was to determine the amount of tilt required. Substituting in the second equation, we have—

$$\epsilon = \sqrt{3.4(.34 + .03) - (4.8 \times .58 \times .17)}$$
$$= .89^\circ = 53'.$$

Therefore, the Polar Axis required to be tilted a little less than a degree towards a point 37° west of north, which corresponds to H.A. $9^h\ 32^m$ west. In the case of the 12½-inch double-yoke mounting, the bottom bearing is provided with adjustment screws for all directions, and it was a simple matter to calculate how many turns of each screw was required to apply the necessary correction. Further

observations on the stars proved that the Polar Axis was correct within the limits of accuracy of the declination scale.

If there is a clear view towards the horizon, it is easy to make the requisite correction, no matter what type of mounting is being adjusted. In the daytime, set the telescope at the Hour Angle indicated—in the above case, $9^h\ 32^m$ west. Move the tube in declination until some well-defined object occupies the centre of the field. Raise the tube the amount indicated by ϵ, e.g. 53′. Clamp the tube and bring the chosen object back to the centre of the field by tilting the whole mounting. Obviously, this effects the desired correction. If the telescope is provided with a drive, the same method could be used on a star, but less easily and not quite so accurately as on a terrestrial object.

Other methods suggest themselves. For example, set the H.A scale at the correct point as indicated by the first equation. Turn the tube horizontal and put a clearly defined mark on the end of the tube—a bit of card with a cross in black ink. Place a surveyor's transit some distance away and centre the mark on the cross hairs. Now raise the tube the required amount in declination, and adjust the mount until the mark is again centred in the transit. Or hang a plumb-line from the upper end of the tube, which should be horizontal as before, and put a marker on the ground to coincide with the point of the plumb-bob. After raising the tube as before, bring the points back into coincidence by tilting the mount. All four methods are based on the same principle.

The astute reader will have realized that the method described is strictly accurate only if the declination axis is exactly at right angles to the polar axis, since the movement of the telescope in declination in observing stars A, B, and C, will introduce an error in the apparent declination readings, but this error is negligible for stars near the equator, even if the declination axis is out of true by a far greater amount than is at all likely with careful workmanship. The error in the declination axis would, however, become very apparent when attempting to pick up stars far removed from the equator. It remains to describe a simple method of performing this necessary adjustment.

To set the declination bearings, select two stars near the meridian, one being near the zenith and the other near the horizon. They should differ in R.A. as little as possible. For example, these stars are suitable:

γ Cygni ..... R.A. $20^h\ 18^m\ 38^s$,
β Capricorni ..... R.A. $20^h\ 15^m\ 24^s$.

The difference in R.A. is $3^m\ 14^s$ with β Capricorni leading. Point the telescope at the leading star and note the exact time when it reaches the centre of the field. A stop-watch and a vertical cross-hair for the main eyepiece are advantageous. Clamp the telescope in R.A. and swing the tube to the declination of the following star. Note the time when this star reaches the cross-hair or the centre of the field. If the interval is too great, the top of the tube must be moved east by altering the bearings. In the case cited, this means that the west bearing must be raised. If the leading star were in the zenith, the east bearing would be raised.

It will be wise to return to our three equatorial stars and check the correctness of the Polar Axis, but it is unlikely that any alteration will be necessary, for the reason already explained. It is hardly necessary to remark that the driving clock, if any, should be disconnected for these tests.

The advantage of the methods just described is that we are establishing a direct relationship between the optical axis—i.e., the field of view—of the telescope, and the stars themselves, which is, after all, the ultimate object to be attained. Its disadvantage is that it must be performed at night.

In conclusion I should like to emphasize the importance of having the prism squared up exactly with the main mirror, and to suggest a simple method by which this may be attained. First we require a prism mounting which will permit of adjustment in all directions. After trying several different designs, the idea shown in the sketch (Fig. 1) was selected for the 12½-inch, as the simplest and most satisfactory. It consists of two discs of ⅛-inch brass, slightly larger in diameter than the diagonal of the square face of the prism. One disc is attached to the end of a rod sliding in the hub of the spider. This provides for longitudinal adjustment. The other disc carries the

prism. A hardwood block, exactly the size of the prism, is attached to the disc by means of flathead wood screws. Two narrow slips of paper are glued to the diagonal face of the block, so that the glass does not touch the wood. The prism is held in place by means of two square plates of thin brass, having small lugs bent over at right angles. These plates are fastened to the sides of the block by wood screws.

The two discs are held together by means of three machine screws. At the centre is a steel ball, resting in depressions in the prism disc

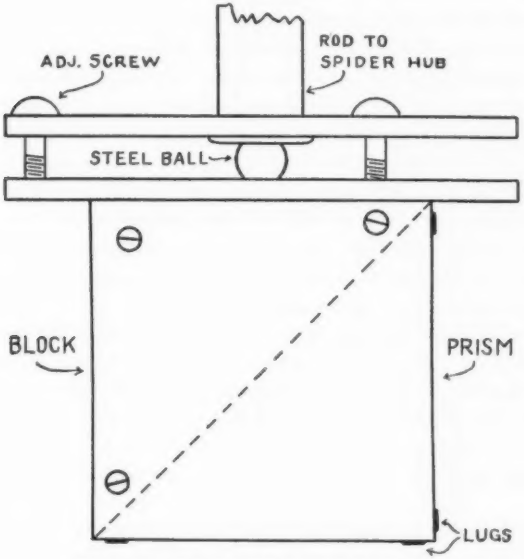


Fig. 1.—Adjustable Mounting for Prism.

and the end of the rod. The prism may be tilted in any direction by means of the screws. All parts should be blackened.

To adjust the prism, turn the telescope tube horizontal, remove the main mirror cell and fasten a piece of cardboard on the end of the tube. The exact centre of the cardboard has a quarter-inch hole. A heavy black cross should be drawn around the hole, on the inside

of the card. Before attaching the card to the tube, lay a flashlight in the tube to illuminate the back of the card. The other end of the tube and the eyepiece must be covered to exclude all light except that from the flashlight.

On looking through the hole in the card, an image of the cross should be seen reflected in the square face of the prism. The adjustment of the prism should be changed until the reflection of the peephole is exactly central. Temporary cross-threads may be provided on the prism face, if desired. This method permits of extreme accuracy, on account of the great length of the incident and reflected rays, and is therefore much to be preferred to the similar method using a target in the eyepiece adapter. It still remains to square the other face of the prism with the eyepiece adapter. Two steps are required: (1) slide the rod in the spider-hub until the eyepiece tube and prism face are concentric. This should be done before starting to square up the prism. (2) Rotate the prism mounting until the face is square with the optical axis of the eyepiece tube. Note that the push-pull screws of the prism mounting must not be changed. Any errror must be corrected by (*a*) rotating the prism in the spider-hub, (*b*) by changing the alignment of the eyepiece adapter.

This matter of squaring up the prism is of vital importance. No telescope can be expected to give optimum performance, no matter how excellent the quality of the optical parts, if these parts are not in proper relationship with each other.

Edmonton, Alberta.

THE SPECTROGRAPHIC ORBIT OF H.D. 34762

By W. H. Stilwell

THE star H.D. 34762 (Boss 1273), $\alpha(1900)$ $5^h14^m.7$, $\delta(1900)+27°51'$, m_v6.30, B9, was discovered to be a spectroscopic binary by R. K. Young from four single-prism spectrograms taken at this observatory in 1919.[1] The first extensive study of this star was made by the writer in 1936 while at the David Dunlap Observatory. The twenty-five plates, having a dispersion of 33.1 A/mm. at $H\gamma$, were obtained at that institution between 1935 December 6 and 1936 March 26, and were measured on a micrometer microscope. The preliminary elements were obtained by the Lehmann-Fihlés method. Two least-squares solutions were made to obtain the final elements. Because of the large scatter of the individual observations about the curve computed from the corrected elements, and because of the relatively small number of observations, it was decided to obtain more plates of this star from time to time in order to try to obtain elements of higher precision.

In December 1940, observing was begun to obtain additional plates in order to redetermine the orbital elements. Dr. F. S. Hogg, at the David Dunlap Observatory, had obtained, in the meantime, fourteen single-prism plates with a dispersion of 63.7 A/mm. at $H\gamma$. These, along with the plates on which the original orbit was based, were kindly sent to the writer. In the interval, 1940 December 16 to 1941 April 4, twenty-nine single-prism spectrograms were obtained at this observatory. Of these, twenty-eight had a dispersion of 30.1 A/mm. at $H\gamma$, and one had a dispersion of 50.8 A/mm. at $H\gamma$. The total number of plates available for this study was seventy-two, of which sixty-nine were used in the final solution. One Victoria plate was rejected because the comparison spectrum was not strongly enough exposed to give sufficiently accurate settings, and two Toronto plates were too weak because of clouds. In all, one hundred and forty-six measures were made of the sixty-nine plates used in the solution. The following persons contributed to these: R. K. Young, 4 (the discovery plates, 1919); J. A. Pearce, 9; R. M. Petrie, 5; and W. H. Stilwell, 128. Each velocity was given a weight which

[1] Publications of Dom. Astro. Obs., *1*, 168, 1919.

depended on the number of lines measured, the quality of the lines and the number of measures of the plate.

In all, four sets of orbital elements were derived. The first, computed at the David Dunlap Observatory in 1936, was based on the observations made at that observatory, and the second, a circular orbit, was based on the 1941 observations made at this observatory and assuming the period of the 1936 orbit. When the combined solution, based on all the observations, was made it was found that the period used in the first two solutions could be improved, using the longer interval, a value of 5.43373 days being preferable to that previously adopted, namely 5.4197 days. This corrected period was used in a new solution, the third, using the 1941 Victoria observations and employing Sterne's[2] method wherein a preliminary circular orbit was assumed and corrected to give a final elliptic orbit.

All the measures made at Victoria were made on a projection micrometer with a screw of 1/2 mm. pitch. Tables using the Victoria system of wave lengths[3] were computed for the Toronto 1-prism 12-inch and 1-prism 25-inch spectrographs so that the measures made here would be be as homogeneous as possible. The spectral lines of this star are broad and diffuse and consequently were difficult to measure with a high degree of precision. This was reflected in the mean probable error of ± 4.7 km/sec. based on a number of the plates. The average number of lines measured per plate was 6.6.

The Solutions

Of the four sets of orbital elements calculated only the details of that based on all the observations are given. The others will be discussed briefly and the final elements given in a table for comparison, but the elements of the combined solution are adopted as the final elements.

The 1936 orbit, calculated at Toronto, was computed by the Lehmann-Fihlés method. The preliminary elements, obtained graphically, were twice corrected by least-squares solutions to give

[2]Proc. Nat. Acad. of Sci., Wash., *27*, 175, 1941.
[3]Publ. Dom. Astro. Obs., *6*, 302, 1936.

the accepted elements for that solution. The first least-squares solution reduced Σpvv by 14.6 per cent. The second least-squares solution gave a further reduction in Σpvv of only 0.05 per cent. The probable error of a plate of average weight was ±12.8 km/sec. However, when the Toronto plates were remeasured at Victoria this value was decreased to ±5.1 km/sec.

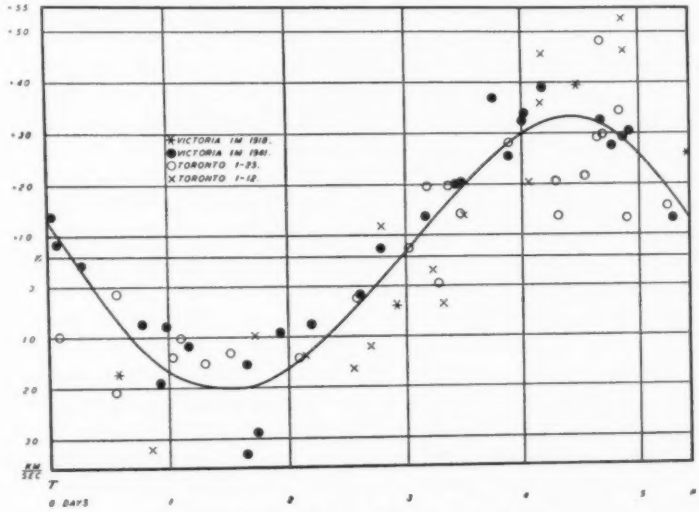


Fig. 1.—Radial Velocity Curve of H.D. 34762.

The first Victoria orbit was undertaken as soon as sufficient observations were obtained in 1941. The preliminary elements were derived graphically. No detectable eccentricity could be seen so a circular solution was made. The twenty-seven Victoria observations were grouped into twelve normal places. The resulting normal equations yielded corrections which, when applied to the elements, caused a reduction in Σpvv of 14.8 per cent. These elements, which proved satisfactory when tested, are shown in the table of elements, Table II, under the heading 1941 (Circular). In this case the probable error of a plate of average weight was ±3.1 km/sec.

Since the individual Victoria observations gave a well-defined velocity-curve it was deemed justifiable to undertake a solution employing Sterne's[2] method. It was desired to see if the observations would yield a slight eccentricity, though none could be detected by an inspection of the velocity-curve, and if an eccentricity were determined how it and the value of ω would agree with the corresponding values obtained from the final solution of the combined observations. The corrected period was used in this solution and the final elements of the circular orbit were taken as the preliminary elements of this solution. Eleven normal places were derived. Normal equations were set up and solved to give the corrections to the elements. The eccentricity was very small, 0.028, and ω was in the right quadrant when compared with the value of ω obtained from the combined solution. A representation of the corrected elements resulted in a decrease of Σpvv of 16.9 per cent. The test showed that these elements were not completely satisfactory so a second least-squares solution was made to confirm the values of e and ω. The Lehmann-Fihlés formula was transformed to adopt it to Sterne's method for small eccentricities[2]. In this solution the corrected elements obtained in the preceding solution were taken as the preliminary elements. New normal equations were formed and solved to get the corrections to the elements. The representation of the corrected elements gave a further reduction in Σpvv of 1.1 per cent. and the substitution of the unknowns in the observation equations indicated a completely satisfactory convergence. The probable error of a plate of average weight was ± 3.2 km/sec.

The combined solution was based on sixty-nine observations which were grouped into twelve normal places. A series of tests, using graphical methods, indicated that $e = 0.05$ and $\omega = 90°$ were probably the best preliminary values. Normal equations were derived and solved to get the differential corrections. The corrected elements were represented and the reduction of Σpvv was 5.7 per cent. The final test indicated a lack of convergence and that a second least-squares solution was necessary. The corrected elements were taken as the preliminary elements of this solution and the normal equations, as shown in Table I, were derived and solved

to give new corrections. The newly corrected elements when represented gave a reduction of only 0.3 per cent in Σpvv. The test for convergence proved satisfactory so these corrected elements were accepted as the final elements of this solution and the probable errors of the elements were computed and are given with the elements in Table II under "Combined." The probable error of a plate of average weight from this solution is ± 5.2 km/sec.

TABLE I

NORMAL EQUATIONS

$$
\begin{array}{rrrrrr}
22.9000\,x + & 2.5253\,y - & 1.0656\,z + & 0.8203\,u + & 0.6172\,v + & 0.5595 = 0 \\
+ 12.6720 & + 0.2487 & - 0.8427 & - 0.8689 & - 0.2298 & = 0 \\
& + 11.7610 & + 1.4731 & + 1.4929 & - 0.8881 & = 0 \\
& & + 10.3484 & + 10.3597 & - 0.1942 & = 0 \\
& & & + 10.4302 & - 0.3432 & = 0
\end{array}
$$

where $x = \delta V_0$

$y = \delta K$

$z = \dfrac{K}{1 - e^2}\delta e$

$u = -K\delta\omega$

$v = \dfrac{Kn}{(1 - e^2)^{1/2}}\delta T$

A comparison of the various solutions indicated that while the orbit is practically circular, nevertheless a slight eccentricity probably exists. The values of e and ω thus derived from the combined solution were accepted as the most accurately determined. The values of K and V_o as given by the various orbits agree within the limits of the probable errors. It seems most satisfactory under the circumstances to accept the elements determined by the Combined Solution as the final set of elements to be adopted for this binary.

Probable Physical Characteristics

Some data concerning the physical characteristics of the components have been deduced from statistical considerations, from the fact that the spectrun of the secondary is not visible, and from assumptions as to the relative masses of the components. From the Russell-Hertzsprung diagram, and the given spectral type of B9,

$$M_v = +0.8$$

TABLE II

ORBITAL ELEMENTS OF H.D. 34762

	1 1936	2 1941 (Circular)	3 1941 (Elliptic)	4 Combined
P	5.4197 days	5.4197	5.43373	5.43373
T (J.D.)	*2428141.195	*2430026.364	2430028.433	2428203.121
	±0.002	±0.024	±1.094	±0.429
ω			49°5 ± 69°6	74°6 ± 28°8
e	0.00	0.00	0.030 ± 0.033	0.076 ± 0.035
K	25.5 ± 2.59 km/sec	26.5 ± 0.62 km/sec	26.4 ± 0.83 km/sec	26.8 ± 0.92 km/sec
V_o	+4.8 ± 1.86 km/sec	+7.2 ± 0.45 km/sec	+7.0 ± 0.61 km/sec	+5.8 ± 0.68 km/sec
$a \sin i$				1995000 km.
$\frac{m_2^3 \sin^3 i}{(m_1+m_2)^2}$				0.011⊙

*Periastron passage was fixed at the time of inferior conjunction of the primary.

from which the bolometric magnitude was obtained through the expression

$$\delta M = M_v - M_B = \frac{29500}{T_e} + 10 \log T_e - 42.53$$

If T_e, the effective temperature, is assumed to be 12000°K, then

$$\delta M = 0.8$$

so

$$M_B = 0.0.$$

From the mass-luminosity relation[4], using the derived value of M_B, we get the mass of the primary equal to three times the mass of the sun. Assuming the secondary to be one, two, or three magnitudes fainter than the primary then masses, corresponding to the magnitudes of the secondary, were obtained from the mass-luminosity diagram[4] and are 2.4⊙, 1.8⊙ and 1.4⊙ respectively. The change of mass is not very greatly affected by the change of luminosity. The ratio of the masses, primary to secondary, is, therefore, not radically different. If the secondary were only one magnitude fainter than the primary it should show some of its stronger lines on some of the spectrograms. If the secondary is assumed to be

TABLE III

PROBABLE PHYSICAL DIMENSIONS

	Primary	Secondary
Magnitudes of components, m_v	6.4	8.4
Absolute magnitudes, M_v	+0.8	+2.8
Masses	3.0⊙	1.8⊙
Inclination of orbit, i	20°	
Semi-axis major	5.7×10^6 km.	9.5×10^6 km.

two magnitudes fainter than the primary then the derived values of its mass and magnitude will be an upper limit or maximum and the value of the inclination, i, will be a minimum. If now the deduced masses of the primary and secondary components are put into the mass function a provisional value of the inclination is obtained. The value of the inclination came out $i = 20°$. Once the inclination is known the actual separation of the two stars may

[4]Kuiper, Ap. J., *88*, 472, 1938.

be determined and in this particular case is about fifteen million kilometers. Provisional values of the masses, luminosities and dimensions based on the above assumptions are given in Table III.

In conclusion the writer would like to express his appreciation to all those who cooperated with him in obtaining the necessary observations for the study of this binary, and especially to Dr. R. K. Young, with whose permission the David Dunlap Observatory plates were made available, and to Dr. F. S. Hogg, who obtained the additional plates between 1936 and 1941 and forwarded all the David Dunlap plates.

Dominion Astrophysical Observatory,
January, 1944.

EDMONTON OBSERVATIONS OF AN OCCULTATION OF JUPITER

By Cyril G. Wates

Three telescopes were used in Edmonton for observing the occultation of Jupiter on the morning of January 13th, 1944. Dr. J. W. Campbell was at the 12½-inch reflector and Mr. E. S. Keeping at the 4-inch refractor, both at the University of Alberta Observatory. The writer was at his 8-inch reflector at the Viewpoint Observatory. The last named almost missed the show, as a Chinook thaw, followed by a hard frost, had clogged the door of the observatory with ice, which had to be chipped away with a screwdriver.

Until about ten minutes before first contact the moon was hidden by heavy cumulus clouds, but these drifted away to the east, and seeing conditions were excellent. Edmonton seems to have been exceptionally favored in the west, as Mr. E. K. White of Chapman's Camp, near Kimberly, B.C., reports that the emersion took place "in a very hazy sky, transparency 2 (scale 0-5), and during my recent visit to Victoria Dr. J. A. Pearce of the Dominion Astrophysical Observatory informed me that the sky was cloudy and no observations could be made. However, Mr. Thomas Hilliard of Worcester, Mass., has written to say that seeing conditions were perfect there.

No attempt was made in Edmonton to record the times of the occultation. Mr. White had requested me to watch for any signs of a lunar atmosphere, and I concentrated on this. I note in the report of the Montreal observers, that Mr. F. P. Morgan saw "something entirely unexpected—a narrow blue band following the rim of the moon, separating it from the planet so that the planet appeared quite detached." Mr. Morgan offers the explanation that it might be due to mirage effect. This was during emersion. Both Dr. Campbell and I observed this effect, and in addition I noted a very marked broadening of the "band" at the limbs of the planet; that is to say, the band was sharply defined at the limb of the moon, but seemed to spread out over the planet, the ends of the band being about twice as wide as the central part. This appearance persisted throughout emersion. Dr. Campbell did not observe this broadening, and neither did Mr. White, but both were struck by the band itself, which was very obvious. We concur in describing the band as "grey", and Mr. White estimates the width of the band as about 5 seconds of arc.

Mr. White has sent my report, with a sketch I made at the time, to Mr. Haas, and we may hope for further comments from the large and enthusiastic group of planetary observers which he represents. Mr. Hilliard makes no remark on such a band, in spite of the excellence of his instrument and the good seeing conditions in Massachusetts, so I assume that it was not visible there. However, the fact that the band was plainly seen at three widely

separated points seems to dispose of Mr. Morgan's theory of mirage, since this would presuppose almost identical atmospheric conditions throughout Canada, which seems very unlikely. On the other hand, if the band was caused by a tenuous lunar atmosphere, this must have been localized at or near the point of emersion, since all three observers who saw the band agree that during immersion the dark limb of the moon crossed the face of the planet as a perfectly sharp line, with no trace of diffusion.

I take the liberty of quoting Mr. Hilliard's time for immersion. 1st Contact, $07^h\ 17^m\ 24^s$. 2nd Contact, $07^h\ 08^m\ 54^s$ L.C.T. (E.S.) Long. 71° 49′ 03″.057 W. Lat. 42° 16′ 39″.998 N.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Astronomical Telescope Finders

Some years ago I had the problem of demonstrating with a refractor telescope in which the finder had no illumination for the cross-hairs and the finder was badly out of adjustment.

I succeeded in turning the main telescope on to a bright star with a low-power ocular and then centring the star in the finder; then I made a further adjustment with a higher power ocular.

I found it very quick and easy to find any visible object (visible to the naked eye) merely by viewing the object with the naked left eye and then, with the right eye superimposing the finder image of the same object on to the naked eye object. In this way objects could be quickly found in the main telescope without any cross-hairs at all.

Since that time I have used this method invariably with my own 6″ reflector and have found it exceedingly efficient. As this method seems to be little known among amateurs, it may be worth while to let it be published from time to time. Fixing broken cross-wires of cobweb is a troublesome job and is rather expensive if done by a craftsman.

L. T. S. Norris-Elye

Manitoba Museum, Winnipeg.

Present State of Sunspot Activity

In the February number of the Publications of the Astronomical Society of the Pacific Dr. Nicholson reviews the sunspot activity for the year 1943. He reports that the number of sunspots decreased normally during the year, and predicts that the current sunspot cycle will reach its minimum about the middle of 1944. The two previous minima were in 1923.6 and 1933.8. Of the sunspot groups observed in 1943, 89 were found to belong to the old cycle, and 6 were attributed to the new cycle. One small group, in December 1942, was possibly also of the new cycle. During 1943 the Mount Wilson observers detected no great magnetic storms. They recorded ten solar flares, or bright chromospheric eruptions, during the year.

The Origin of the Carolina Bays

The Carolina Bays are a series of many oval craters in the coastal plain of South Carolina and adjacent states. The origin of these craters is a problem of great geological interest. Some time ago a theory was developed that the craters were produced by the impact of a swarm of thousands of meteors, coming in from the north-west, and producing these craters, which, in general, run in a north-west to south-east direction. Several years ago various evidence led most students of meteoritic problems to discard this tempting theory as to the origin of these craters. The problem has thus been returned to the geologists.

In the January number of the American Scientist, pp. 1-22, Professor Douglas Johnson, of Columbia University, gives a very excellent account of the methods of research on this problem. He presents the evidence which confirms the improbability of explaining the craters on a meteoritic hypothesis. He then outlines a complex "solution-artesian-lacustrine-aeolian hypothesis" to explain the observed phenomena. He suggests that the craters may have been formed "in part from the solution of soluble rock formations and in part from the removal of sand by artesian springs; that wave action on lakes within the craters reshaped their shores and built some of their sandy rims; and that wind action built up the major rims partially surrounding the outer margins of the craters."

Post-War Astronomical Plans in the U.S.S.R.

Reconstruction plans in the Soviet Union call for both the rebuilding of observatories destroyed by the passage of warfare, and for establishment of larger new observatories. While Pulkovo observatory buildings have been previously reported as being completely destroyed, we now learn that most of the observatory library and instruments were removed for safety before the battle approached. It is assumed that this is the case with the equipment of some of the other observatories destroyed.

In the new plans astrophysical work will be centred at Simferopol, the recently liberated capital of the Crimea. Three observing stations, two in Russia and one probably in Africa, will have as their principal instruments one 120-inch reflector, and two 80-inch reflectors. Other telescopes will include two 16-inch astrographic refractors, one 50-inch and one 30-inch Schmidt cameras, solar tower telescopes and a coronagraph. Plans also include training the large staffs of astrophysicists who will be needed to operate this project. The plans apparently call for not only a lavish, but a very well-balanced, expansion of astronomical research facilities.

F.S.H.

MEETINGS OF THE SOCIETY

AT TORONTO

October 12, 1943. The Society met at 8.00 p.m. in the McLennan Laboratory, University of Toronto; Miss R. J. Northcott in the chair.

W. G. Colgrove, M.A., B.D., of the Society's London Centre, winner of the Chant Medal in 1942, addressed members and guests on "Some New Aids in Teaching Astronomy." Set up for demonstration and inspection were five of the devices originated by the speaker and now being turned out for use in schools and colleges at the Hume Cronyn Memorial Observatory, University of Western Ontario.

"My idea in building these gadgets has not been to mystify anyone but by elimination of every possible part and cog to produce devices to illustrate the elements of astronomy to the student and beginner. I learned long ago that to copy Nature is impossible. In producing these teaching aids every effort has been made to simplify them. Astronomy is hard to teach to beginners but these devices, while not copying Nature, do demonstrate it in simple ways," Mr. Colgrove said.

The first instrument demonstrated was a planetarium to show the relationships between the planets themselves and the planets and the sun. To keep the device within practical limits, Mr. Colgrove explained, five different scales were used; diameters of the inner planets were in proper ratio in one scale, those of the outer planets were in ratio on a much smaller scale. Referring to the name of the instrument, Mr. Colgrove pointed out that the word planetarium is improperly applied to buildings such as those in New York, Chicago, and Philadelphia. A better name, he suggested, would be "star theatre."

The second model was designed to show how the planets in travelling through space move faster than is indicated on a plane diagram showing an orbit around the sun. "It illustrates that the planets move in corkscrew paths around the sun as the sun itself travels through space, and that the planets really move much farther in a period of time than is shown in textbooks," he said.

The third device shown was the *sotellunium*, a mechanical sun-earth-moon system which demonstrates the orbital revolutions of the earth and moon, solar and lunar eclipses, inclination of the earth's equator and the cause of the seasons, midnight sun and midday night at the poles, and many other phenomena.

A fourth device showed the relative position of the sun and the 50 brightest stars, the latter represented by tags at the ends of wires radiating from the "sun," the lengths of the wires indicating the distances of the respective stars, one inch being equal to 32 light years. The fifth model shown was one of the galaxy illustrating the central condensation and spiral arms, with the position

of the solar system in one arm, and the interstellar matter which prevents us from viewing the nucleus of the galaxy.

The Chairman referred to the death on October 6 of Mrs. Chant, wife of Dr. C. A. Chant. On motion of Mr. J. R. Collins, seconded by Mr. T. H. Mason, the Secretary was instructed to send a letter of sympathy to Dr. Chant on behalf of the Centre.

Miss R. J. Northcott then presented the first of a series of short reviews on "Fundamentals of Astronomy," intended particularly to acquaint new members with the use of the Society's *Observer's Handbook*.

The Greeks recognized 48 constellations but these did not cover the entire sky, and 10 per cent of the stars catalogued in Ptolemy's *Almagest* were not within the borders of these constellations. The spaces between the ancient constellations have now been filled in and 88 constellations are recognized. The boundaries of the constellations, originally irregular, were revised in 1928 by the International Astronomical Union and follow circles in the sky similar to latitude and longitude circles of the earth.

About 60 of the brighter stars have names of Arabic, Greek or Latin origin. Most of the naked-eye stars have been designated by Greek letters preceding the name of the constellation, the letters usually being assigned in order of brightness from *alpha* on. Many catalogues, listing more than one million stars and including all those (except in the Milky Way) visible with a three-inch telescope, have been published. These catalogued stars are designated by an abbreviation representing the title or author of the catalogue and a serial number. Some stars are known by name, constellation and Greek letter, and several catalogue numbers.

The present scale for designating brightness of stars by magnitudes is based on that used by Hipparchus 2,000 years ago. Hipparchus listed the brightest stars as first magnitude, the faintest visible to the eye as sixth. With the advent of the telescope, fainter stars were seen and the scale had to be extended. Early in the 19th century measurements of brightness were made and it was found that stars of successive magnitudes really differed by approximately equal ratios. By taking average brightness of all stars of the first and all of the sixth magnitudes, it was determined that a star of magnitude 1 was 100 times as bright as one of magnitude 6. Thus a star of a given magnitude is 2.512 times brighter than one of the next lower magnitude. By using this light ratio the scale of magnitudes can be extended in both directions. Now, by international agreement, decimal places are used to indicate brightness of stars between the standard magnitudes. Stars brighter than the standard first magnitude are classed as of zero or minus magnitudes; e.g., Canopus, —0.86; Sirius, —1.58. The planet Venus may become brighter than mag. —4, while the sun is about mag. —26.7. The largest telescope now in use shows stars down to the 21st magnitude or 100,000,000 times as faint as a star of first magnitude.

FREDERIC L. TROYER, *Recorder.*

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1890-1943

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